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ENVIRONMENTAL EFFECTS AND REDUCTION OF CEMENT USAGE DURING THE MECHANICAL ACTIVATION PROCEDURE FOR RESIDUE BASED SULPHATIC TAILINGS TREATMENT

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ABSTRACT:

The huge sector for hazardous solid waste is sulfuric mine tailings, which are highly toxic heavy metal-containing waste. Improper treatment of tailings can lead to heavy metal transfer emissions into the environment and acid mine drainage. Therefore, mechanical activation was employed in this study to successful immobilization of heavy metals and repurpose a mixture of carbon tailings (T_P) and sulphate tailings (T_A) for concrete construction. Based on the test for toxic behaviour in the samples, leachate test was carried out and it results in less leachate rate than the permitted rate. The procedure to conduct leachate was called as Toxicity Characteristic Leachate procedure (TCLP). In the porosimeter test, the result of the surface area was increasing, and the porosity was decreasing respectively. In the 20% sample of activated tailing replaced with cement, the diameter of the pore after 28 days of curing was 60nm and this was very less than the critical diameter which was 150nm and the compressive strength was 31.2 MPa. The ettringite and the Ca, Si hydration gel was needed to stabilize the metal pollutant, and it was shown by XRD and SEM results. Overall, in this research, the combined tailings which was activated mechanically could replace 40% of the cement to make concrete samples. Aside from reducing cement consumption, the combined approach used resulted in a reduction of the negative impact of sulphide content in concrete samples.

1. INTRODUCTION

1.1 General Instructions

The tailings from mine contains very minute particles, between 2µm and 2mm. Tailings are difficult to manage properly because their behaviour varies with size and requires careful design, construction and maintenance as well as the footprints for disposal facilities (Lottermoser, 2010). The characteristics of tailings can differ based on the location and the ore type which is used for recovering important components. Tailing has hazardous elements like copper, zinc and lead (Akcil et.al., 2006). Moreover, precious elements are taken from sulphide mineral, leaving behind significant amounts of tailings rich in sulphides. When tailings are reacted to water and air it produces acids which are more dangerous to the environment (L. Wang el.al., 2017). The environment's pH is lowered by the Acids that are produced, and the heavy metals solubility and mobility are increased in the tailings (Saedi et.al., 2022). If this process is carried out, the environment will be exposed to hazardous substances like highly toxic and cancer-causing arsenic oxyanions (Park etl.al., 2019). Even after the mine is closed, the acids can have a significant negative impact on the environment over time. Thus, it is crucial and essential to mitigate the environmental impact by implementing effective techniques and particularly the tailings which have sulphide (Kefeni et.al., 2017). The usual methods for managing mine tailings are either to dump them directly or to store them in specialized buildings called tailings dams. On the other hand, tailings dam stability worries mine owners. According to earlier research multiple dam failure occurred due to mishandling of tailing particles and mine usage (Saedi et.al., 2017). The recent proof of catastrophic tailing dam failure caused irreversible environmental and human damage.

Therefore, more research is essential, and it is required to determine an effective and long-term solution for the process of consolidating and stabilizing the tailings. The highly active pozzolanic solid waste, namely GGBS, and the rice husk ash were used to investigate the effective stabilization of chromium, lead, and cadmium in Pb-Zn tailing in much research (W. Wang et.al. 2017). More than 99 percent of those three minerals were successfully stabilized, according to the results. There was a notable decrease in the concentration of these elements of roughly 97.04%, 99.56%, and 99.58%, respectively, in the available fractions. Leaching rates of those three minerals in various samples were less than the National standards of China, indicating that the use of RHAs and GGBS in the tailings produced excellent stabilization performance (Kiventer, 2019).

The result of a study shows that the process of hydration on Calcium Sulphate Alumina-belite cement produced mono-sulfate and ettringite, which had efficient oxyanion and sulphate stabilization properties. After seven days of curing, the toxic components like cationic and anionic components were incapacitated successfully (Ghazi et.al., 2022). The binder exhibited high mechanical strength and sulphate immobilization during 50 percent of overall tailings weight. And the mechanical strength and stability significantly decreased at 75 and 90 percent

of tailing weight. Portland cement-based stabilization of gold mine tailing was studied by Rachman. According to the observation, a blend of 10% Portland cement and 89% tailing produced a compressive strength that was at least 2.522 MPa higher than the necessary level. Additionally, the toxic characteristic leach procedure (TCLP) revealed a much lower level of metal leaching than the required threshold (Barzegar, 2022). While prior research has examined the stabilization and solidification of mine tailing, little is known about the stability and solidity of high sulphatic tailing, particularly those with elevated sulfide concentrations in lead and zinc tailings (Rico, 2008). These tailings have high sulfide concentrations and present serious obstacles to the effective immobilization of hazardous elements and the stability and solidification processes, in addition to raising environmental concerns.

2. MATERIALS AND METHODOLOGY

2.1 Materials

The tailing used in this research came from the mine. The sulphide tailings (TA) came from Rajasthan, India while the carbonate tailings (TP) came from the Zawar Mine in Rajasthan, India. The aggregate in this case was natural sand, and the binder was Portland cement. To determine the sulphide concentration in the tailings, the Laboratory Equipment Corporation (LECO) method was used (Azam, 2012). The sulphide precipitation of the TA tailing was approximately 19.8%, whereas the TP tailings showed a sulphide content of about 0.41%. Table 1 displays the TA and TP's chemical compositions as ascertained by XRD analysis.

Constituents	SiO_2	CaO	K_2O	Al_2O_3	Fe_2O_3	Na_2O	MgO	TiO_2	MnO	P_2O_5	SO_3	Pb	Zn	L.O.I
T_P	7.50	50.80	0.14	0.58	0.77	0.28	0.61	0.03	0.3	0.01	0.3	0.18	1.14	37.94
T_A	4.49	5.48	0.43	1.58	10.68	0.73	1.20	0.13	0.27	0.21	49.90	0.13	1.16	23.08

Table 1. The initial chemical makeup of T_P and T_A

The TA tailings was determined as a high-sulphide tailings after an XRD analysis which resulted in 49.90% of SO3 content significantly. This significant issue with mine tailing stability is the presence of sulphur-rich compounds. The TP tailing content of 50.80% in CaO was high and the issue was addressed for economic factors. Mechanical activation was used to combine the sulphide and carbonate tailings to mitigate the environmental impact through efficient reuse of tailings.

2.2 The Activation of Tailings and the stabilization of mixing plan.

Environmental Protection Agency (EPA) recommends toxic character and leaching test procedures to assess the rate of heavy metal pollutants which was leached and the efficacy of the process of stabilization. The leaching rate of heavy metals were examined using an inductive coupled plasma mass spectrometer. In continuation of the examination, the results were related to the Environmental protection agency standards (Barati, 2020). The stabilized specimen was tested using XRD method to survey the phase changes brought about by mechanical activation. For the analysis, monochromatic copper-graphite radiation was used. The scanning view was varying from 3θ between 6ºC and 78ºC, the scanning speed was fixed at 0.024s for every step. And Thermogravimetric analysis (TGA) was taken at heat rate of 15°C/min in the atmosphere of nitrogen. The 400 to 1000°C temperature range was covered by the analysis. The sample hydration products were analysed under a Scanning electron microscope. Porosimeter instrument was used to calculate the cumulative pore volume and pore size distribution. The Fourier transform infrared analysis was carried out and it results in 4000 - 350cm^{-1} to observe the molecular character and the process of hydration (H. Wang, C et.al, 2022)

3. RESULT AND DISCUSSION

3.1 Investigation of the tailings by XRD method

The outcome of the XRD results on stabilized specimens with 20% and 80% of tailings in the replacement of cement as shown in Figure 1a and 1b. Figure1a) shows the stabilized tailings' XRD spectra following a 28th day curing period.

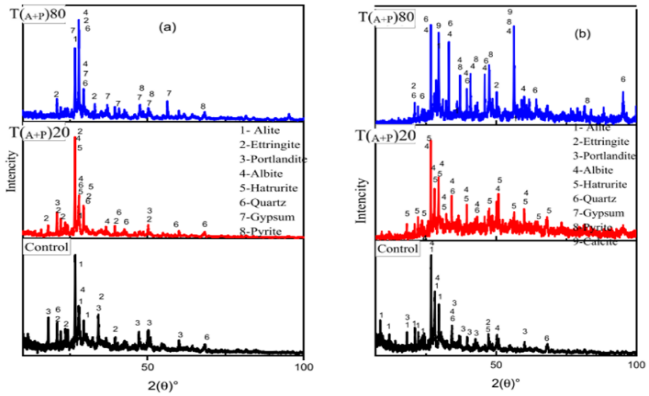


Figure 1. Analysis of XRD for the stabilized samples after a) at 28 days b) at 90 days

The peaks in the c100 sample show that phases like portlandite, ettringite, and alite were developed for the cement's hydration. Figure 1b shows the stabilized tailings' XRD spectra following a 90th day curing period. c100, the initial formation of ettringite and portlandite phases was noted for T(A+P)20 sample (Table 2). Nevertheless, alite a hatrurite transition occurred, resulting in the appearance of the high level at 2θ = 25.66, 26.10, and 28.47. Ettringite showed a higher intensity at 2θ = 26.99 for T(A+P)80 sample.

Sample	cement (kg/m^3)	sand (kg/m^3)	Tailing T(A+P) (kg/m^3)	Water (kg/m^3)
c100	589.1	1586.5	0	290
T(A+P)20	469	1586.5	116.5 (34.25+82.25)	290
T(A+P)40	351.5	1586.5	236 (71.5+164.5)	290
T(A+P)60	234	1586.5	352.5 (105.7+246.7)	290
T(A+P)80	115.5	1586.5	471 (141+330)	290
T(A+P)100	0	1586.5	588.5 (177.2+411.2)	290

Table 2. Preparation of the mix samples

In the beginning stage of the curing process, ettringite formation is not an issue; however, over time, it may cause the concrete matrix to expand. Sulphur compounds like pyrite were found in T(A+P)80 sample, which had a higher tailings content. Gypsum

was another byproduct of the carbonates and sulfides reaction (Kiventer et.al., 2019). The duration of curing of the sample increased from 28 days to 90 days, as shown in Fig. 1b, the peaks linked to hatrurite became more pronounced for the T(A+P) 20.

This points to the sample's anticipated strengthening. The phases that resulted from hydration of cement were not found in the sample of T(A+P) 80. Rather, a notable existence of sulfide-containing mineral salts, like pyrite and ettringite, was noted. The samples expanded and cracked as a result of the presence of these sulfide salts. Moreover, sulphate compounds might also target the samples (Rachman et.al., 2018). In general, the XRD results in the stabile samples shed light on variables affecting the variations in the strength of strength.

3.2 Toxic character and leaching test procedure

For investigating the effectiveness of tailing stability/solidity process, the Toxic Character and Leaching Procedure (TCLP) test were examined. After 28th day and 90th day of curing, the carbonate and sulphide combination in tailing without the activation process T(A+P) sample, T(A+P) 80 sample, and T(A+P) 20 samples are presented in Table 3.

Element/ metal	Combined tailings T(A+P) (µg/ l)	T(A+P) 20 28days (µ g/ l)	T(A+P) 80 28days (µ g/ l)	T(A+P) 20 90days (µ g/ l)	T(A+P)80 90days (µ g/ l)	Standard Limit (µg/ l)
Cu	67.14	28.89	54.3	19.2	40.17	3502
Zn	33,310	801	15,620	652	10,220	16,020
Pb	2331	251	623	192	511	55,020
Ni	177	69.28	163	5.12	141	2602
Cr	79.42	46.34	71.2	23.3	55	3802
Cd	52.05	2.66	13.3	1.6	8.11	762
As	45.05	4.72	42	1.3	5.2	4502

Table 3. The leachate rate of heavy metal in T(A+P) and the 20 and 80 percent of activated tailing samples after 28th and 90th days of curing

The findings showed that the combined tailings leachate of the heavy metals was below permitted limits. On other hand, the leachate rate for zinc was higher than the permitted limit, measuring 33,310 µg/l as opposed to 16,020 µg/l. All metal leaching rates decreased noticeably as the samples' curing times lengthened after stabilization and solidification. Following stabilization, the zinc leaching rate in T(A+P), which had previously surpassed the standard limit, likewise decreased. The rate at which metals leached, on the other hand, increased with the quantity of tailings. As a result, the leaching rate in T(A+P) 80 sample was greater than in T(A+P) 20 sample.

The stabilization process significantly enhances the preservation of heavy metals in sulfide tailing, according to the overall results of the TCLP test. The cement mixture matrix's ability to have metal pollutant was aided by the samples of concrete for construction. Ettringite, Carbon, Silica and hydrogen gel, which are formed during the process of hydration and play a key role in neutralizing heavy metal ions through the process of adsorption, are among the causes. Table 3 demonstrates that the leach rate of each heavy metal under study was below the standard limit in each stabilized sample. It was noted that the number of tailings increases which led to a drop in hydration products and increases the leachate rate in the samples that contained Ts sulphatic tailings, that has sulphides. As a result, the environmental outcomes were improved by the application of mechanical activation and tailings treatment, which significantly reduced the rates at which metal contaminants leached.

3.3 Pore size distribution analysis

An additional technique for examining the solidification effectiveness of mine tailings is the Mercury Intrusion Porosity (MIP) test (Kiventer,2019). The results of Porosity after 28th and 90th days for c100 sample, T(A+P) 80 sample, and T(A+P) 20 sample are shown in Figure 2. For T(A+P) 20 sample of Porosity was about 47.1 mm^3/g, as shown in Figure 2a. This is less than the leaching rate of about 70 mm3/g that was noted for the control sample (c100). This shows a decrease in porous when 20% activated tailings were substituted for cement.

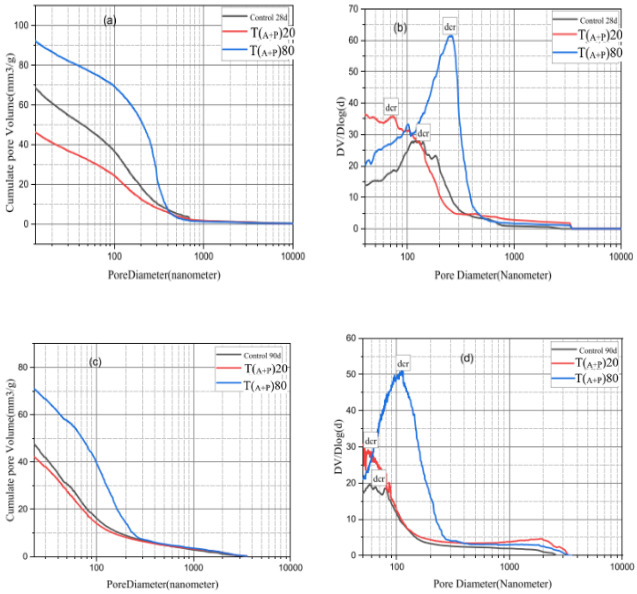


Figure 2. a) T(A+P)20 sample - 28th day of curing, b) T(A+P)80 sample- 28th day of curing, c) T(A+P)20 sample - 90th day of curing, d) T(A+P)80 sample- 90th day of curing

The volume of mercury intrusion in T(A+P)80 sample was greater than that of c100 sample, at about 90 mm^3/g. The pore size distribution graph in figure 2b shows the sample with 20 percent activated tailings had a critical pore size (CPS) of about 59 nm. And it is noteworthy that the control sample's pore size was 149 nm. The effect of tailings treatment in reducing pore size is demonstrated by this notable decrease in the pore size. The CPS in T(A+P)80 sample was roughly 500 nm. The mercury consumption is shown in Figure 2c, where T(A+P)20 sample showed a consumption of about 39 mm^3/g, or about 16% less than c100 sample. And the mercury consumed in the MIP test decreased as the number of curing days increased.

The successful stabilization and solidification were accomplished through the activated tailings and making of hydration products, which enhanced the cohesiveness of the different samples (Rachman, 2018). Mercury consumption in T(A+P)80 sample was 68 mm3/g, and it is less than the specimen's after 28th day of curing. The pore size distribution diagram in Figure 2d shows that the critical pore in T(A+P)20 sample was finer than c100 sample, at about 20 nm. This suggests the existence of less harmful pores appropriate for building applications. Overall, results show that the activation of tailings

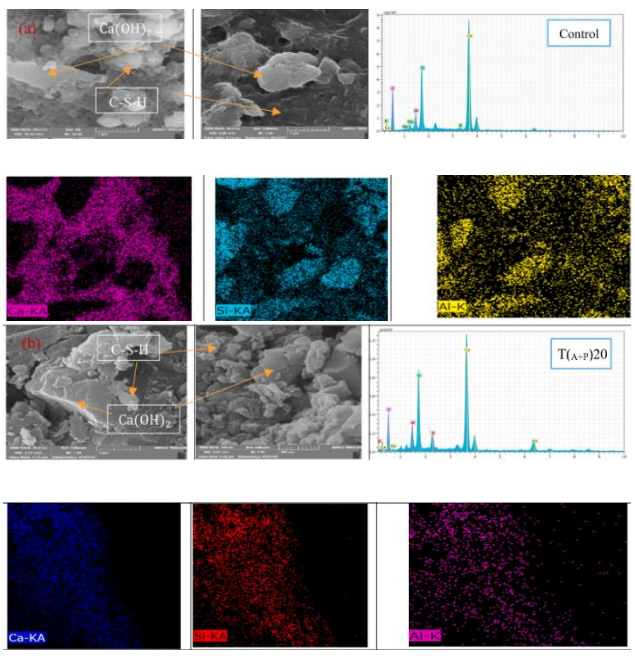
reduced porosity, shrank critical pore size, and enhanced cohesiveness, all of which helped the samples stabilize and solidify (Chen et.al., 2010).

Approximately 100 nm was the critical pore size (CPS) for T(A+P)80 sample. The concrete expanded as a result of the sample's high sulfide compound contents, which also raised pores and consumption of mercury. The other samples which was under investigation, longer curing times resulted in better cohesiveness and lower consumption of mercury, demonstrating the efficiency of the stability procedure. And in conclusion, when 20% of the cement was replaced, the stabilization/solidification process was more effective because the mechanical activation process increased the combined tailings' reactivity.

This was demonstrated in T(A+P)20 sample, where the mercury consumption volume and CPS were both less than those of the control group. The outcomes show that effective stabilization/solidification was achieved by increasing the tailings mixture reaction through mechanical activation. The lower critical pore size and the consumption of mercury in T(A+P)20 indicate that the strategy of substituting the tailings which was activated at 20 percent ratio with the cement was effective in producing the desired outcomes.

3.4. The Analysis in SEM

The SEM, mapping and EDx analysis and the result of c100, T(A+P) 80, T(A+P) 20 and their hydration are shown in Fig. 3. The control sample's SEM, mapping and EDx are shown in Figure 3a. The C-S-H gel and portlandite plates makes the stabilized tailings. They create a compressed lattice structure by decreasing the specimen's voids and pores. The image of T(A+P)20 following 90 days of curing of stabilization/solidification was shown in Fig. 3b. According to the SEM images, the sample had a Ca/ Si ratio of roughly 3, which suggested the advantage in the presence of $Ca(OH)_2$ and C-S-H (Rachman, 2018).



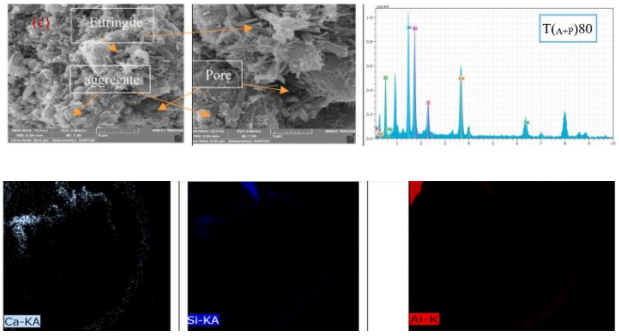


Figure 3. Phase formation in the materials as determined by SEM, EDx, and mapping: samples of a) c100 sample, b) T(A+P) 20 sample, and c) T(A+P) 80 sample following 90 days of curing

The C-S-H bonded the particles in the sample together, which was anticipated to increase the sample's overall strength. Higher concentrations of Ca, Si, and Al were produced by activating tailings, and these materials were evenly distributed across the stabilized sample, and to give a uniform texture (based on the analysis of mapping). Greater hydration product production resulted from the constituent compounds' increased reactivity following the mechanical activation process (Chen el.al., 2012). Images of T(A+P) 80 sample are displayed in Figure 3c, which suggests a calcium to silica (Ca/ Si) in the ratio of roughly 1.21. And T(A+P) 80 sample showed more pores and cracks than T(A+P)20. This is explained by the fact that the sample contains more unreacted silica than T(A+P)20 sample, which leads to less hydration product formation. Pyrite and ettringite, two sulfur compounds, were present in the sample because the tailings utilized were sulfidic (Chen et.al.,2012).

These substances lengthened the sample's hardening period, which resulted in expansion and a reduction in compressive strength. To outline, the result of the SEM and the EDX analysis demonstrated the uniform distribution of the ingredient compounds on the sample surface was the consequence of mechanical activation followed by stabilization/solidification of tailings. The stabilization process was most reactive and more effective overall as a result of this uniform distribution. The availability of hydration products beneficially reduced the leach rate of toxic elements, though the creation of hydration products decreases, and the sulfur compounds increases with the increase in the quantity of T_A and T_P.

In summary, combination of stabilization/solidification processes with mechanical activation produced a number of advantageous results in the tailings. These included the production of hydration products, an appreciable decrease in the leach rate of toxic elements, and the developed distribution and reaction of the component compounds. It's crucial to remember that, despite certain difficulties like higher sulfur compounds and less hydration product formation, the process was clearly effective overall in reducing environmental risks (Saedi etl.al., 2023).

3.5. Compressive strength

Figure 4 shows the compressive strength of the stabilized samples obtained by employing activated tailing with altered percentages of 20, 40, 60, 80, and 100 percentages during different days of curing. According to the results, after three curing days, the compressive strength of T(A+P)20 sample was

11.4 Mega Pascal, which was less than c100 (13.2 MPa). Nevertheless, the compressive strength also rose as the curing days were raised.

The sample's compressive strength after seven days of curing was 24.11 MPa, higher than the control sample's measurement of 18.6 MPa. And after 28th and 90th day of curing, sample's mechanical strength was 31.2 and 39.7 MPa, respectively. After three and seven days of curing, the compressive strength of T(A+P)40 sample was comparatively low. Reduced hydration products and longer curing days were the results of the significant quantity of tailings in the primary curing stage. On the other hand, the compressive strength considerably increased to 27.32 after 90th day of curing. The compressive strength decreases as the quantity of tailings increases for T(A+P)100 sample, T(A+P)80 sample and T(A+P)60 sample. Raising the tailings content in stabilized concrete samples led to the sample cracking and expanding over longer curing days, resulting in a decrease in compressive strength. This was due to Ts which are sulfidic and were present in the samples in larger quantities than the tailings of carbonate

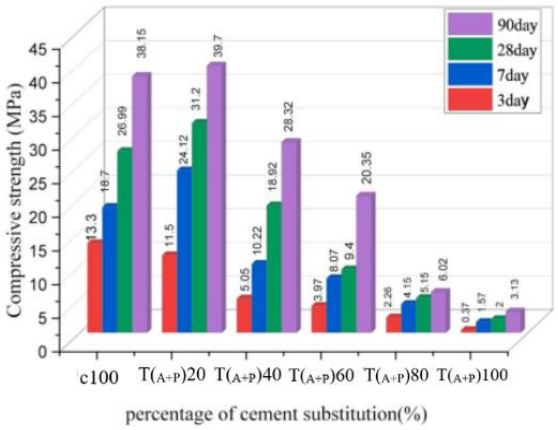


Figure 4. Compression strength of T(A+P) samples after 3rd, 7th, 28th and 90th day of curing

It is noteworthy that even with the significant decrease in compressive strength at alteration rates exceeding 40 percentage, the strength obtained at alteration was up to 80 percent in 28th and 90th day of curing and exceeded the typical limits of stabilizing (Ili´c et.al., 2018). Consequently, this can be stated that the treatment of sulfide with carbonate tailings through mechanical activation resulted in reuse of the tailings for concrete construction purposes and cement replacement (up to 40%). While the less strength of the concrete samples was a minor disadvantage, their extremely low metal leaching rate made them a reasonable option. In the end, the rate at which metals leached from such concrete samples did not increase due to the decrease in hydration products. Based on the XRD result presented in Section 2.1, the formation of sulfidic compounds was responsible for the lower compressive strength of samples with high amounts of tailing after 28 days of curing.

3.6. The Analysis of Fourier Transform infra spectroscopy

The stabilized specimen's FTI spectra following 28th and 90th day of curing are shown in Figure 5a and Figure 5b. Ettringite and C-S-H formation were linked to the peak at 3395.45 and 3451.46 for the sample T(A+P)80 and T(A+P)20 sample respectively. In the control sample, the C-S-H and portlandite were attributed to the peak at 3648.41. The peak in T(A+P)80 at 2515.78 was linked to S-H bonding. The examined sample were formed more deeply in T(A+P)80 had peaks at 1438.30, 1441.10, and 1435.63, respectively, which represented the stretch of vibration of CaO and the OCO bonds. This might have happened because the stabilized sample with a high tailings content lacked hydration products, which would have reduced the reactivity of the CaO during the curing days (Kindi et.al., 2019).

Due to asymmetric sulphate vibration, the peak of at 1091.62 and 1092.61 in T(A+P)80 sample and T(A+P)20 sample were linked to the quartz and the formation of the ettringite, which suggested OCO bond. With T(A+P)80 sample, it was more intense. C-S-H bond was linked to a peak at 1006.20, 1004.76, and 1025.30 in the sample c100, T(A+P)80 sample, and T(A+P)20 sample, respectively.

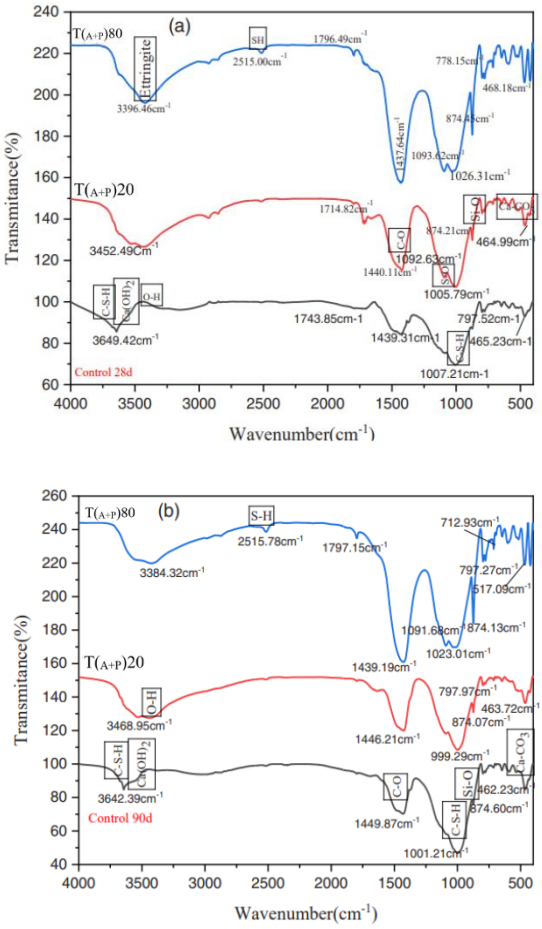


Figure 5. FTI spectra data of the stabilized samples with T(A+P) after 28 and 90 days of curing, with 20% and 80% cement replacement, respectively

The CaO and SiOSi bonds were identified as the symmetric stretching vibrations responsible for the peak at 873.20 and 873.45 for T(A+P)20 sample and T(A+P)80 sample, respectively. These peaks are less intense for T(A+P)20 and were not seen in the c100. Therefore, it is possible to propose that the stabilized T(A+P)80 contained a significant amount of unreacted $CaCO_3$ and silica phases, which would corroborate the sample XRD patterns. The specimen's FTI spectra follows 90 days of curing. Those graphs are nearly identical to the 28th day of curing graphs, as the figure 5 illustrates, and there is no discernible difference in the peaks that are displayed. The stabilized sample, which contained

20% tailings, showed peaks involved in the evolution of hydration products that were similar to those of the c100, based on the FTI spectra diagrams. Moreover, higher intensity peaks associated with ettringite (one of the sulfur compounds) were seen in the stabilized sample that contained 80 percent tailings. The graphs differed from the c100 sample due to the presence of these compounds. The peak appears are assigned to the hydration products which shows the proper result of stabilization and the tailings treatment through mechanical activation, whereas the intensity of the peaks in the stabilized tailings varies with amounts of cement substitutions.

3.7. Thermogravimetric Analysis

Four regions correspond to the loss of weight in the dry samples. The first temperature range, which is between 20 and 25°C, mainly incorporated with the loss of water molecules that are bonded to the phase of hydration of samples, including stratlingite, ettringite, and C-S-H. In between 250◦C and 400◦C, the 2nd temperature range where the calcium silica alumina hydrate (C-A-S-H) phase breaks down. The 3rd temperature range, roughly 400◦C - 500◦C, is where calcium hydroxide is dehydrated. Finally, the decarburization and the breakdown of C-S-H into a wollastonite are the characteristics of the 4th temperature level, which is between 698°C and 800°C. (Cyr et.al. 2014). T(A+P) showed a loss of weight of about 4 percent for the temperature inculpation from 20°C to 198°C in Figure 6a.

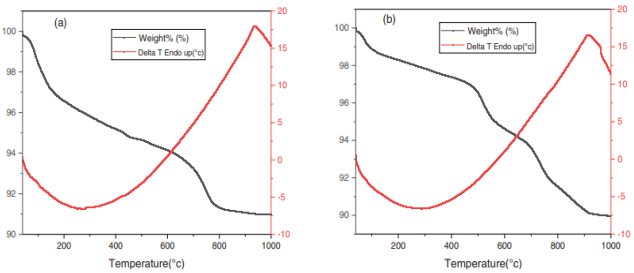


Figure 6. Following 28th day of curing, the TG-DTA curves for (a) T(A+P) 20 sample and (b) T(A+P) 80 sample

The water molecules released are bonded within the C-S-H and ettringite phase and it is responsible for the observed weight loss. Those hydrated phase become dehydrated during the heating process, which causes them to lose water and consequently lose weight. A progressive loss of weight was seen, with a drop of about 7%, between 198°C and 698°C. The loss of weight took place in the range of temperatures where portlandite and C-S-H phase decompose. So, the TG analysis clearly shows that the sample underwent changes and lost weight during the tailing's activation. The loss of weight showed a steeper slope at temperatures above 698°C, which was linked to the sample's carbonate phases decaying. Due to the dehydration of C-S-H and the loss of free moisture, a weight loss peak was identified at 248°C.

Overall, the TG analysis results in losing weight and the thermal behavior of T(A+P) at various temperature ranges, as well as the breakdown of particular phases that are present in the sample and dehydration processes. This peak might overlap with the breakdown peak of ettringite and mono sulfo alumina hydrate, per earlier research. The weight loss of the stabilized T(A+P) 80 sample is shown in Figure 6b. This loss was about 1.5% up to 99◦C, which was linked with C-S-H's dehydration. There was a small weight loss (roughly 2%) in the 100 - 500◦C range. This was because the specimen contained a large amount of tailings, which reduces the amount of product hydration in the sample.

There was a greater increase in weight loss at temperatures over 500°C. The samples' $CaCO_3$ phase decay was linked to this weight loss. The peak observed at approximately 298◦C can be ascribed to the C-S-H phase in the decaying T(A+P) samples. The loss of weight of T(A+P)80 sample and T(A+P)20 sample was insignificant, it can be concluded. This is explained by the tailings high-energy activation, which caused weight loss in the process of activation. The tailings lost some volatile compounds, like CO_2, during the activation process and then went through the stabilization process (Saedi et.al., 2023). The weight loss in T(A+P)80 was notably less than that in T(A+P)20. The increased tailings content in the stabilized sample accounts for this variation in weight loss. Higher concentrations of tailings, which contain sulfur compounds, decreased the concrete sample's pozzolanic qualities, which in turn decreased the hydration products of cement (Akin et.al., 2023). At higher temperatures, the rate and the quantity of weight loss in the concrete sample was reduced due to the creation and availability of sulfidic compounds, which prevents the water from evaporating.

4. CONCLUSIONS

The usefulness of treating tailings by mixing carbonate and sulfide tailings and using mechanical activation was examined in this work. The findings produced a number of noteworthy conclusions:

1. By activating combined tailings and building concrete samples, the rate at which heavy metals leached gradually dropped over time until it was below the established limits. This result indicates that the activation process in conjunction with tailings effectively lowers the environmental risks related to mine tailings. The leaching rate of metals was not negatively impacted by substituting activated tailings for cement in order to reduce cement consumption. This suggests that in the stability process, mechanical activation can effectively replace cement.

2. T(A+P)20 sample showed improved structural integrity with increase in cohesion and decrease in the pore volume, according to the MIP analysis. Then, T(A+P) 80 sample underwent expansion, increased porosity, and increased consumption of mercury due to its higher sulfide content. The stabilized samples' sustained improvement of compressive strength was facilitated by the combined tailings' activation. Notably, the compressive strength of every concrete sample with 20 to 80 percent tailings exceeded the quality requirements needed for stabilization and solidification. The study's conclusions showed that the stabilization/solidification procedure, which included mechanical activation, successfully lowered the rate at which heavy metals leached. Furthermore, the use of cement was significantly reduced by 20% thanks to this method. The availability of relative peaks in the T(A+P)20 sample was discovered by Fourier transform infrared (FTI) spectra analysis, suggesting the formation of hydration products. These outcomes supported the successful creation of hydrated products in the stabilized sample and were in line with those seen in the control sample.

3. Visual proof of the homogeneity and dense structure of the stabilization samples was given by XRD, EDx analysis, mapping, and SEM. The compounds from the activated tailings were found to be evenly distributed across the samples, demonstrating how well the stabilization procedure worked to achieve this goal. Sulphide tailings mechanical activation process raised their

reactivity, which in turn improved their pozzolanic qualities and made them a respectable cement substitute. Stated differently, the non-reactive material mine tailings underwent a transformation into activated tailings, which can serve as a medial alternate for cement in the construction of concrete. Finally, these results provide compelling evidence for the efficacy of mechanical activation as a tailings treatment method, presenting encouraging future directions for mine tailings management. In addition, the decrease in cement usage improved the samples' strength in addition to being advantageous for the stabilization and solidification processes. To optimize the process further and to reduce the consumption of cement, future research can be conducted to investigate the amalgamation of different activation methods or by incorporating additives such as silane.

References

A. Akcil, S. Koldas, Acid mine drainage (AMD): causes, treatment and case studies, J. Clean. Prod. 14 (2006) 1139–1145, https://doi.org/10.1016/j. jclepro.2004.09.006

A. Barzegar Ghazi, A. Jamshidi-Zanjani, H. Nejati, Utilization of copper mine tailings as a partial substitute for cement in concrete construction, Constr. Build. Mater. 317 (2022),125921, https://doi.org/10.1016/j.conbuildmat.2021.125921.

A. Saedi, A. Jamshidi-Zanjani, A.K. Darban, M. Mohseni, H. Nejati, Utilization of lead–zinc mine tailings as cement substitutes in concrete construction: effect of sulfide content, J. Build. Eng. 57 (2022), 104865, https://doi.org/10.1016/j.jobe.2022.104865.

A. Saedi, A. Jamshidi-Zanjani, M. Mohseni, A.K. Darban, Effect of mechanochemical activation on hydration properties of lead-zinc sulfide tailings for concrete construction, Case Stud. Constr. Mater. 18 (2023), e01996, https://doi.org/10.1016/j.cscm.2023.e01996

A.B. Ghazi, A. Jamshidi-Zanjani, H. Nejati, Clinkerisation of copper tailings to replace Portland cement in concrete construction, J. Build. Eng. 51 (2022), https://doi.org/10.1016/j.jobe.2022.104275.

Akin, C., Preethi, V., Experimental Analysis of Bubble Deck Slab and Its Application for Sustainability in the Ecology Dimension, Lecture Notes in Civil Engineering, 2023, 346 LNCE, pp. 493–499, https://doi.org/10.1007/978-981-99-2552-0_40

Alieh Saedi, Ahmad Jamshidi-Zanjani, Mechanical activation for sulfidic tailings treatment by tailings: Environmental aspects and cement consumption reduction, Case Studies in Construction Materials 19 (2023) e02632, https://doi.org/10.1016/j.cscm.2023.e02632

B.G. Lottermoser, Introduction to mine wastes, in: in: Mine Wastes, Springer, Berlin Heidelberg, 2010, pp. 1–41, https://doi.org/10.1007/978-3-642-12419-8_1.

B.Ili´c, A. Mitrovi´c, L. Mili˘ci´c, M. Zduji´c, Compressive strength and microstructure of ordinary cured and autoclaved cement-based composites with mechanically activated kaolins, Constr. Build. Mater. 178 (2018) 92–101, https://doi.org/10.1016/j.conbuildmat.2018.05.144.

G.Y. Al-Kindi, Evaluation the solidification/stabilization of heavy metals by Portland Cement, J. Ecol. Eng. 20 (2019) 91–100, https://doi.org/10.12911/22998993/99739

H. Wang, C. Ju, M. Zhou, J. Chen, Y. Dong, H. Hou, Sustainable and efficient stabilization/solidification of Pb, Cr, and Cd in lead-zinc tailings by using highly reactive pozzolanic solid waste, J. Environ. Manag. 306 (2022), https://doi.org/10.1016/j.jenvman.2022.114473.

I. Park, C.B. Tabelin, S. Jeon, X. Li, K. Seno, M. Ito, N. Hiroyoshi, A review of recent strategies for acid mine drainage prevention and mine tailings recycling, Chemosphere 219 (2019) 588–606, https://doi.org/10.1016/j.chemosphere.2018.11.053.

I.A. Chen, C.W. Hargis, M.C.G. Juenger, Understanding expansion in calcium sulfoaluminate-belite cements, Cem. Concr. Res. 42 (2012) 51–60, https://doi.org/10.1016/j.cemconres.2011.07.010

J. Kiventer¨ a, K. Piekkari, V. Isteri, K. Ohenoja, P. Tanskanen, M. Illikainen, Solidification/stabilization of gold mine tailings using calcium sulfoaluminate-belite cement, J. Clean. Prod. 239 (2019), https://doi.org/10.1016/j.jclepro.2019.118008.

J. Kiventer¨ a, Stabilization of sulphidic mine tailings by different treatment methods: heavy metals and sulphate immobilization. in: Tesiss C 721, University of Oulu, Faculty of Technology Acta Univ. Oul., 2019, p. 2019.

K.K. Kefeni, T.A.M. Msagati, B.B. Mamba, Acid mine drainage: prevention, treatment options, and resource recovery: a review, J. Clean. Prod. 151 (2017) 475–493, https://doi.org/10.1016/j.jclepro.2017.03.082.

L. Wang, B. Ji, Y. Hu, R. Liu, W. Sun, A review on in situ phytoremediation of mine tailings, Chemosphere 184 (2017) 594–600, https://doi.org/10.1016/j. chemosphere.2017.06.025

M. Cyr, M. Trinh, B. Husson, G. Casaux-Ginestet, Effect of cement type on metakaolin efficiency, Cem. Concr. Res. 64 (2014) 63–72, https://doi.org/10.1016/j.cemconres.2014.06.007

M. Rico, G. Benito, A.R. Salgueiro, A. Díez-Herrero, H.G. Pereira, Reported tailings dam failures. A review of the European incidents in the worldwide context, J. Hazard. Mater. 152(2008)846–852, https://doi.org/10.1016/j.jhazmat.2007.07.050.

R.M. Rachman, A.S. Bahri, Y. Trihadiningrum, Stabilization and solidification of tailings from a traditional gold mine using portland cement, Environ. Eng. Res 23 (2018) 189–194, https://doi.org/10.4491/eer.2017.104.

S. Azam, Q. Li, Tailings dam failures: a review of the last one hundred years, Geotech. News 28 (2010) 50–53, https://doi.org/10.1373/clinchem.2008.105395.

S. Barati, P. Tabatabaie Shourijeh, N. Samani, S. Asadi, Stabilization of iron ore tailings with cement and bentonite: a case study on Golgohar mine, Bull. Eng. Geol. Environ. 79 (2020) 4151–4166, https://doi.org/10.1007/s10064-020-01843-6.

W. Wang, Y. Shao, H. Hou, M. Zhou, Synthesis and thermodynamic properties of arsenate and sulfate-arsenate ettringite structure phases, PLoS One 12 (2017), https://doi.org/10.1371/journal.pone.0182160.